Development of High Power Amplifiers for Space and Ground-based Applications

The power amplifier used in the transmitter of a microwave system is a key issue, and it determines the system performance, cost, power consumption and reliability to a considerable extent. Traditionally, most of high power amplifiers used in military and commercial applications were tube-based amplifiers. They are efficient and provide very high power levels operating at low duty cycles. But they have a questionable long term reliability, large footprints and they are not suitable for modern equipment with a decentralized transmitter, like a phase array system. Solid State Power Amplifier technology is the alternative to the tube-based amplifiers. Recently, there has been a renewed interest in this research field thanks to a large extent, to the development of GaN semiconductor technology, that is already having an important impact on the wireless and radar market.

The scope of this PhD dissertation lies in the development of nonlinear design methodologies, manufacturing, and efficient testing of Solid State High Power Amplifier modules, with special focus on GaN state of the art technology. It is possible to identify two types of GaN Solid State High Power Amplifiers: the Hybrids and the Monolithic Microwave Integrated Circuits. The research work presented here focuses on practical realization and demonstration of these two types of amplifiers. The design and experimental performance assessment of 50W Solid State C-band High Power Amplifier using European Monolithic Microwave Integrated Circuit GaN technology is discussed. The design will be used as a baseline for future developments of the next generation of the Sentinel satellite remote sensing radar T/R modules. The two stage design features a 6730 X 3750 µm² compact footprint. The overlapping between simulated intrinsic drain current and voltage waveforms is minimized, thus providing good power added efficiency. The design process encompasses a wide range of activities including technology assessment, small and large signal model validation using load pull measurements, nonlinear harmonic balance simulations, stability analysis, matching network synthesis, evaluation of spreads and high power testing. The design has been fabricated at the United Monolithic Semiconductors foundry using their 0.25 µm gate length GaN process, which currently is under final development.

Pulsed high power measurements provided excellent results. The maximum average power level measured under pulsed operation was 53 W at 4.74 GHz, and the maximum overall PAE measured was 55.8% at 4.9GHz. The device presents a good bandwidth under large signal operation. At 1.2dB compression point, in the frequency range from 4.85 GHz to 5.3 GHz, the output power is larger than 40 W (46.75dBm +/- 0.25 dB) with the gain ranging around 19 dB. This corresponds to a 0.5dB bandwidth of 450MHz. PAE varies between 50%-54% along all this frequency range. These measurements present state of the art efficiency at C-band for these power levels achieved with a single chip.

An efficient 100 W X-band hybrid high power amplifier using 0.25 µm gate length GaN technology was successfully designed, assembled and tested. The goal of the project was to develop a high power amplifier for X-band frequencies with capabilities to replace the vacuum tubes used in the radar systems designed by Terma, the company co-funding the project. These radars are purely civilian systems used for applications like traffic surveillance within airports, coastal and air surveillance, environmental surveillance of sea surfaces and vessel traffic monitoring in harbors. The design process included technology evaluation, load pull and harmonic balance simulations, bondwire array and transition electromagnetic modelling, die attach, device fabrication and testing. Outstanding results were obtained for a single stage hybrid design using a power bar with 20 mn active area periphery. 94.5 W were measured under pulsed operation at 8.3 GHz and with a gain of around 7.6dB. The maximum power added efficiency obtained was at >60%. This efficiency is higher than any other published for these power levels at X-band. Limited bandwidth was achieved. Along the 200 MHz band between 8.1 to 8.3 GHz, and at 1 dB compression point, the device was delivering power levels larger than 75 W, PAE >35% and gain oscillating between 7.5 +/- 0.5 dB. Measurements were shifted down in frequency 1 GHz, but simulations predicted maximum power levels similar to the ones measured.